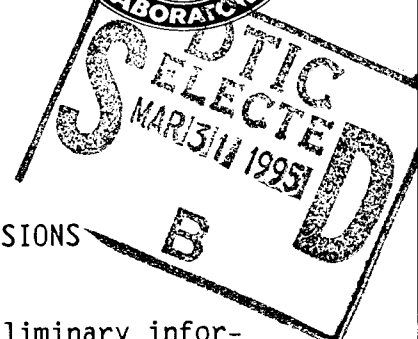# *Environmental Effects of Dredging*
Technical Notes

ECONOMIC OPTIMIZATION OF CONFINED DISPOSAL AREA DIMENSIONS

PURPOSE: The purpose of this technical note is to present preliminary information on selecting dimensions for confined dredged material disposal facilities to obtain minimum cost for land and dikes.

BACKGROUND: Confined disposal facilities must be sized to provide adequate volume to store the disposed sediments and to meet effluent water quality standards. Given a sediment volume, designers may select CDF dimensions (length, width, ponding depth, and lift thickness) from wide ranges that meet both storage and water quality constraints. This note provides guidance on selecting these CDF dimensions to achieve minimum cost.

ADDITIONAL INFORMATION: This technical note was prepared by Dr. F. Douglas Shields, Jr. with input from Drs. Paul R. Schroeder and Michael R. Palermo. For additional information, contact Dr. Shields, (601) 634-3707, or the manager of the Environmental Effects of Dredging Programs, Dr. Robert M. Engler, (601) 634-3624, for additional information.

Introduction

The most recent Corps of Engineers guidance for confined disposal facility (CDF) design, Engineer Manual 1110-2-5027 (Headquarters, US Army Corps of Engineers 1987), provides a method for determining the minimum required site area and volume given a mean ponding depth ($\bar{d}$) and pond length-to-width ratio (L/W). Total cost is not considered. In cases where the shape and area of available land are not severely constrained, the designer may select a combination of diked area and height (CDF dimensions) to provide the required volume at minimum total cost. The approach described in this technical note will allow a designer to select CDF dimensions that will result in CDF costs substantially less than those that result from straightforward application of the EM guidance.

Limitations

The method described here is applicable to rectangular CDFs only. If the available land at the CDF site is not the right shape or is not big enough for the least-cost rectangular design determined using this procedure, the procedure can still be used to select the least-cost alternative rectangular design that does fit the site. Furthermore, application of this guidance will often result in smaller land area requirements, particularly where land costs are high. This method is not limited to designing new CDFs; it can also be used to select the most economical way of configuring an existing CDF to receive a given flow and still meet effluent standards.

A CDF designer must select pond length, width, and depth and decide whether to use spur dikes and, if so, how many to use. The first step in sizing the CDF is to determine the volume the dredged material will occupy in the CDF at the end of the last disposal event. If the CDF design is for one cycle of filling, drainage, and drying, the results of a long-term column settling test (Figure C-2, p C-6, EM 1110-2-5027) may be used to determine dredged material volume. In certain cases, the nomograph in Figure 1 of TN EEDP-02-8 may be used instead of results of a long-term column settling test to determine dredged material volume. If the CDF design is for several cycles of use, consolidation calculations will also be needed (Chapter 5, EM 1110-2-5027).

Once final dredged material volume is determined, the required dike height is determined by dividing dredged material volume by pond area to get lift thickness and adding pond water depth and freeboard. The cost for land for the CDF may be reduced by decreasing the pond area and increasing the dike height to handle the greater lift thickness. However, dike volume, and thus cost, is a geometric function of dike height. In addition, as dike height increases, the land area required for the dikes themselves also increases. For some value of pond area (and the associated required dike height), the total cost, which is approximately the sum of dike cost plus land cost, is minimized. However, CDF dimensions must also meet maximum dike height and water quality constraints if they are to be used. If minimum cost dimensions result in a design that fails to meet the dike height or water quality constraints, additional analysis of costs can be performed to determine the least cost design that does satisfy the constraints. Details follow.
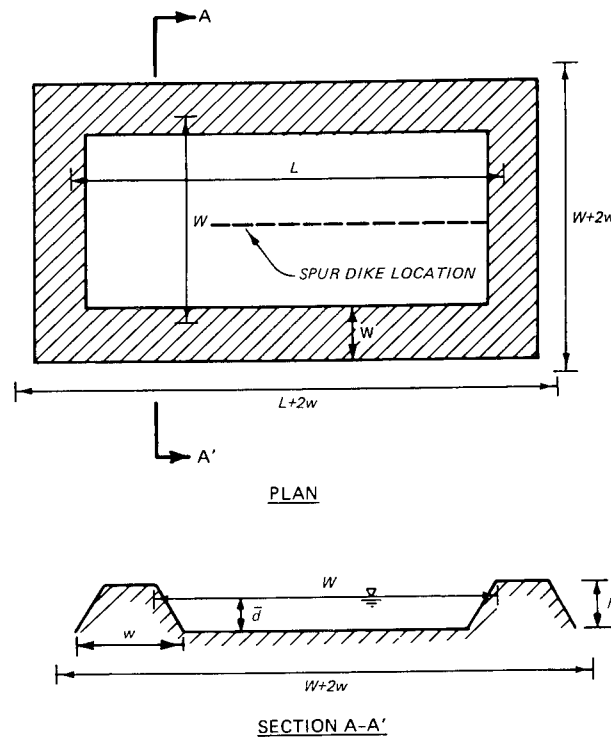
Figure 1. Definition sketch of CDF--
assumptions are given in Table 1

Development and Use of Diagram

Unless water quality constraints control design, least-cost CDF dimensions may be read from a simple diagram. The diagram consists of plots of the controlling dimensionless variables. In order to develop the diagram, controlling dimensional variables are identified. CDF cost is a function of the volume of material to be disposed; its settling characteristics; dike design parameters; the price of land and dikes; the mean flow rate; the number of spur dikes; and the CDF length, width, and dike height. The number of variables can be reduced by assuming a constant crown width and side slope for the perimeter dikes and by forming dimensionless groups of the remaining variables.

In order to illustrate diagram development and use, a simple CDF site configuration was assumed. Basic assumptions used in setting up the problem are given in Table 1, and dimensionless variables are defined in Table 2. A schematic of a CDF is provided in Figure 1 to aid interpretation of Tables 1 and 2.

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Table 1

Assumptions

Minimum ponding depth, $\bar{d}$ = 2.0 ft

CDF cost = total land cost + total dike cost
(This implies that weir costs and other costs are negligible, and relocation and right-of-way problems do not affect site shape or size)

Volume of dredged material in CDF at end of disposal, V_m = 100,000 yd^3

The dredged material exhibits settling characteristics shown in Figure 2 (from EM 1110-2-5027)

Dike design:

Maximum dike height = 20 ft

Crown width = 10 ft

Side slope = 1V:3H

Freeboard = 2.0 ft

The site in question is level enough that dikes with uniform cross section have constant crown elevation.

The cost for dikes is simply a constant unit price times the embankment volume.

The price of spur dikes per unit length is 0.5 times the price per unit length of perimeter dikes (U_s = 0.5).

Spur dikes are 0.8 times as long as the length of the pond (L_s = 0.8).

As shown in Table 2, seven basic dimensionless variables were formed. An eighth dimensionless term, the hydraulic efficiency correction factor (HECF), which is a function of two of the seven dimensionless variables, is also important in problem solution. Meanings of four of the seven dimensionless terms are further explained below:

P* is the dimensionless ratio of the price of land to the price of perimeter dikes.

Q* is the dimensionless mean flow rate into the CDF.

V* is a dimensionless measure of the CDF surface area. It is also the ratio of mean ponding depth to dredged material lift thickness.

Table 2

Formulas for Spreadsheet

Dimensionless Variables

$$P\star = \frac{\text{unit price of land, } U_l}{\text{unit price of dike fill, } U_d} \times (V_m^{1/3})$$

$$Q\star = \frac{\text{mean flow rate, } Q \times \text{time required for settling, } t_{req}}{V_m}$$

$$V\star = \frac{(\text{pond length, } L) \times (\text{pond width, } W) \times (\text{mean depth, } \bar{d})}{V_m}$$

L/W = pond length divided by pond width

$L/\bar{d}$ = pond length divided by mean depth

= number of spur dikes

HECF = hydraulic efficiency correction factor

$$HECF = \frac{1}{[0.9 \ (1 - \exp(-0.3(L/W)L_s(\# + 1)^2)]} \quad \text{-- from Shields et al. (1987)}$$

$$(L_s = 1 \text{ when } \# = 0)$$

$$C\star = \frac{\text{total CDF cost}}{V_m U_d}$$

Dimensional Variables

$$\text{lift thickness} = \frac{V_m}{L_s W}$$

dike height, h = lift thickness + pond depth + freeboard

dike width, w = dike crown width + 2(h/side slope)

side slope = vertical dimension/horizontal dimension

$$\text{dike cross-sectional area, } A_d = (\text{dike crown width v h}) + \frac{h^2}{\text{side slope}}$$

pond length, L = $V\star V_m(L/W)/\bar{d}$

(Continued)

Table 2. (Concluded)

pond width, $W = L/(L/W)$

land area required for CDF = $(L + 2w)(W + 2w)$
  (this allows for a strip of land (h - 2/side slope) wide around the outer perimeter of the CDF as shown in Figure 1)

cost for land = $U_1 \times$ land area required for CDF

length of perimeter dikes, $P_{dl} = 2(L + 2w + W)$

length of spur dikes, $S_{dl} = 0.8 \ L \times$ number of spur dikes

price of perimeter dikes per unit length = $U_d A_d$

price of spur dikes per unit length = $0.5 \ U_d A_d$

cost for dikes = $U_d A_d \ (P_{dl} + 0.5 \ S_{dl})$.

total CDF cost = cost for land + cost for dikes

Effluent Water Quality Constraint

$$V^* \geq HECF \times Q^*$$

Dike Height Constraint

$$h \leq 20 \ ft$$

A designer calculates P^* and Q^* from given conditions. He varies L/W, V^*, d, and $\#$ to minimize C^*, yet still meet dike height and water quality constraints.

C^* is the dimensionless unit cost of the CDF. It is the ratio of the cost per cubic yard of the CDF to the price per cubic yard of perimeter dikes.

The absolutely least costly CDF design features minimum ponding depth and is square (L/W = 1.0) with no spur dikes. For such a design, C^* is a function of V^* and P^* only. Microcomputer spreadsheets are ideal for computing C^* values for a range of V^* and P^* values. Results may be plotted as shown in Figure 3. To use the diagram, a designer selects V^* that minimizes C^* for the P^* value applicable to the project. LW ($LW = L^2 = W^2$) may then be calculated from V^* (Table 1) and $d = 2.0 \ ft$. Dike dimensions may then be obtained from the formula in Table 1.
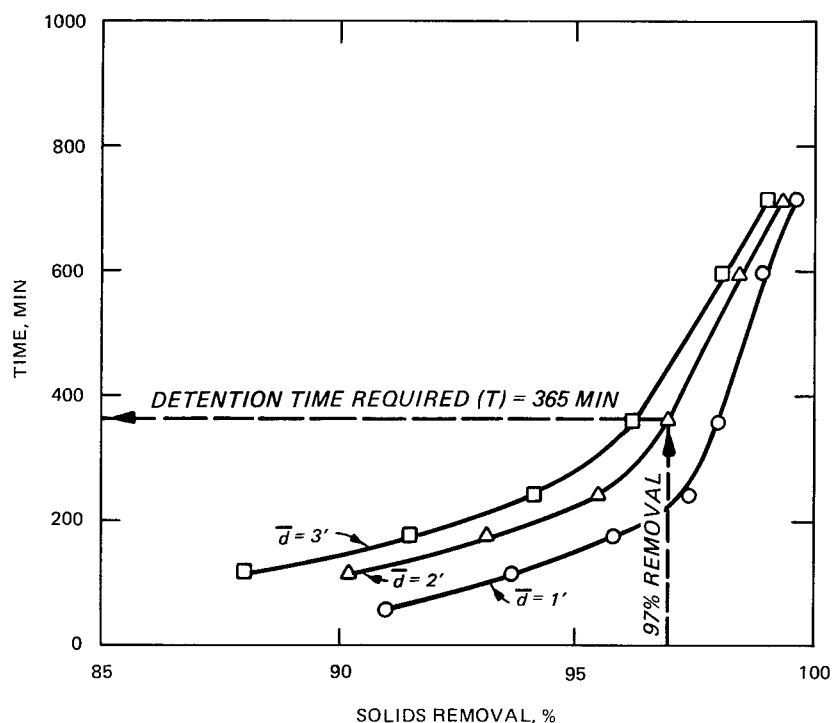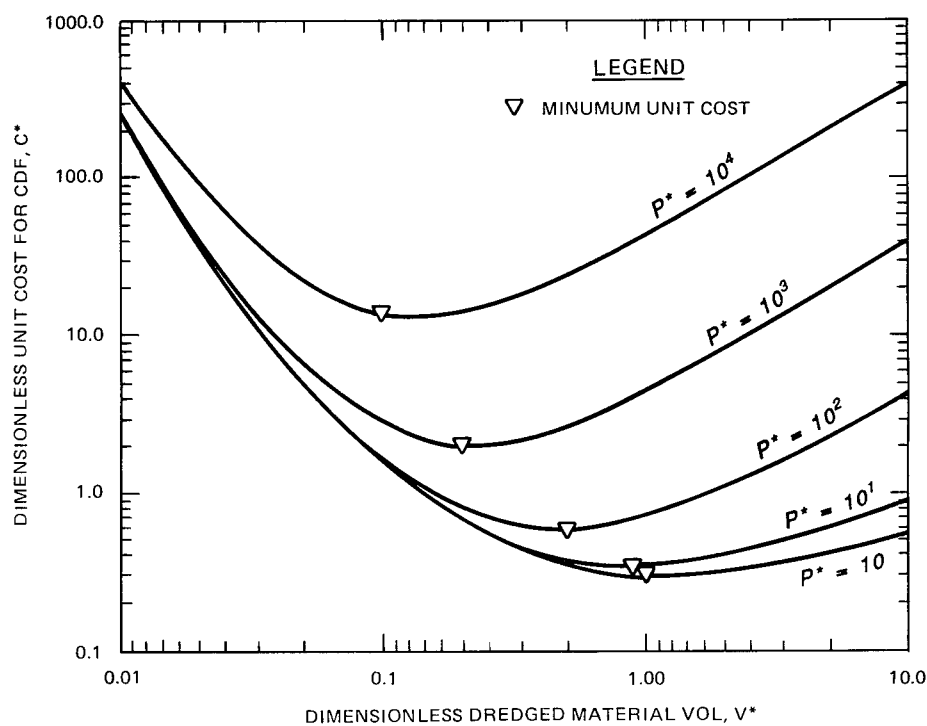
Figure 2. Settling data for dredged material

Figure 3. Dimensionless cost for CDF, C* as a function of
dimensionless unit price ratio, P* and dimensionless final
dredged material volume, V*

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Area Constraint

If the area required for the CDF design obtained from a diagram like Figure 3 is too large for the available land parcel, the least-cost design configuration may be obtained by simply using the entire available area and setting dike height equal to lift thickness plus 4 ft (ponding depth and freeboard of 2 ft each).

Dike Height Constraint

Least-cost design configurations from analyses like those that produced Figure 3 must be checked to ensure that they meet dike height and effluent water quality constraints. Dike height may be expressed as a function of V^* . Under the assumptions in Table 1, V^* must be greater than or equal to 0.125 for the dikes to be less than 20 ft high. All least-cost configurations in Figure 3 meet the dike height constraint. Values of P^* higher than those shown in Figure 3 do produce minimum C^* values that violate the stated dike height constraint.

Water Quality Constraint

Least-cost design configurations must also be checked to ensure that they meet the effluent water quality constraint. Basically, the water quality constraint is that the CDF hydraulic mean retention time should exceed the time required for clarification that is determined from laboratory column settling tests. In terms of the previously defined dimensionless variables this constraint may be stated $(V^* / HECF) \geq Q^*$.

If the least-cost design configuration from Figure 3 fails to meet the water quality constraint, the mean retention time must be increased. CDF mean retention time may be increased by (1) reducing the mean flow rate, (2) increasing pond surface area LW , (3) increasing mean ponding depth, (4) increasing L/W , or (5) using spur dikes. Additional spreadsheet analysis may be used to determine which of these five approaches is the most cost effective. Repetitive calculations can be performed to determine the effect of varying Q^* , V^* , ponding depth, L/W , and the number of spur dikes on C^* . Penalty functions can be used to generate large unit costs when total

land area, dike height, or water quality constraints are not met. Results of a series of such spreadsheet analyses are presented in Table 3. Spreadsheet formulas should allow for the fact that increasing the ponding depth slightly reduces the required retention time for flocculent suspensions, as shown in Figure 2, and thus also reduces $Q^* = Q\ t_{req}/V_m$ (Table 2).

Table 3 shows that least-cost designs for the assumed conditions call for slight increases in L/W with increasing P* and favor the use of spur dikes when large values of both P* and Q* occur. Less expensive spur dikes like floating baffles (Shields et al. 1987) would favor increasing the number of spur dikes over increasing L/W . Current prices (1988) for floating baffles are about $20 per linear foot. In some cases, baffles may be reused.

As would be expected, Table 3 shows that larger flow rates require larger surface areas and higher land prices favor using less surface area. In other words V* , the dimensionless pond surface area, varies directly with Q* and inversely with P* .

Table 3
Least-Cost* Design Configurations for CDFs

Price Ratio P*	Flow Rate Q*	Surface Area V*	L/W	No. of Spur dikes #	Mean Pond Depth, ft $\bar{d}$	Unit Cost C*
1	0.03	1.125	1.0	0	2	0.303
1	0.30	1.300	1.0	0	2	0.304
5	0.03	1.025	1.0	0	2	0.321
5	0.30	1.300	1.0	0	2	0.325
10	0.03	0.925	1.0	0	2	0.342
10	0.30	0.925	1.5	0	2	0.348
100	0.03	0.475	1.0	0	2	0.587
100	0.30	0.550	1.0	1	2	0.626
1,000	0.03	0.200	1.0	0	2	1.994
1,000	0.30	0.350	1.5	2	2	2.345

* Based on assumptions in Table 1.

Mean ponding depth for examined conditions was always equal to 2.0 ft for minimum cost. Changing the settling characteristics of the dredged material suspension toward slower settling or increasing the unit price ratio above 10,000 would favor greater ponding depth.

Example

A CDF is to be designed for a disposed volume of 100,000 cubic yards with basic assumptions as shown in Table 1. Land costs $3,000 per acre and perimeter dikes may be constructed for $2.60 per cubic yard of dike volume, giving $P^* = 100$. Available dredges range in size from 8 to 27 in. Assuming dredge pumping averages 14 hours per day and using a pipeline velocity of 15 fps yields $0.03 < Q^* < 0.3$. Least-cost design configurations are shown in Table 4. Table 4 shows that unit cost increases with Q^* when Q^* exceeds the V^* value for least-cost design from the diagram in Table 3. Figure 4 shows the effect of mean flow rate on minimum unit cost and on unit cost for a "standard" design with $L/W = 1.0$ and dike height = 8.0 ft.

Table 4

Example--Least-Cost CDF Design

Dredge Size in.	Mean Flow Rate cfs*	Pond L ft	Pond W ft	d ft	Total Area for CDF acres	Number of Spur Dikes	Lift Thickness ft	Dike Height ft	Unit Cost $/yd^3
8-18	3-13	801	801	2	19.4	0	4.2	8.2	$1.53
20	16	822	822	2	20.2	0	4.0	8.0	$1.53
27	30	862	862	2	21.8	1	3.6	7.6	$1.63

* This mean flow rate is an average for the entire period it takes to fill the CDF. Mean flow rate was calculated by multiplying dredge pipeline cross-sectional area times pipeline velocity times (100% - percent downtime). Pipeline velocity was assumed to be 14 fps and downtime was assumed to be 10 hours/day, or 42 percent.
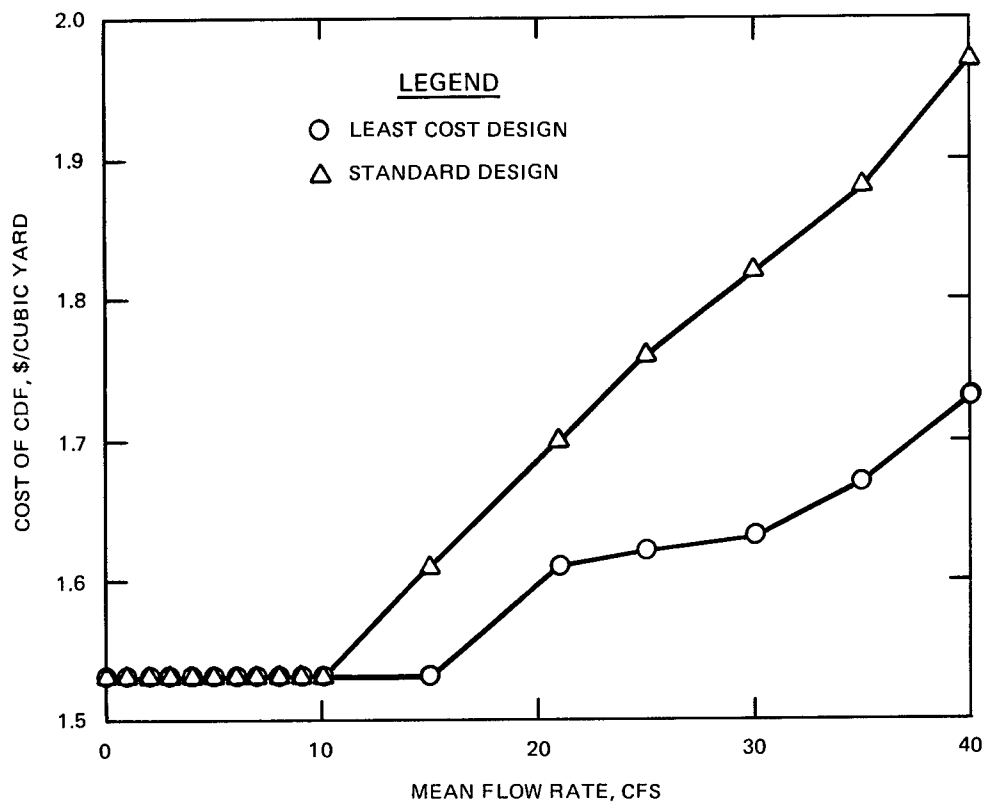
Figure 4. Effect of mean flow rate on CDF unit cost,
least cost design and "standard" design with L/W =
2.0 , dike height = 8.0 ft, and no spur dikes

Summary and Conclusions

Over the range of conditions most commonly encountered, economically optimum CDF designs have no spur dikes, have low perimeter dikes, are square, and have a mean ponding depth of 2.0 ft. Surface areas for these designs may be obtained by reading V* from Figure 3 and calculating LW. As the relative price of land to perimeter dikes (P*) increases, the optimum design configuration entails higher dikes and less total land area, length-width ratios between 0 and 1.5, between 0 and 2 spur dikes, and a mean ponding depth of 2.0 ft. To avoid short-circuiting, square CDFs (L/W = 1.0) should either have inflow and outflow points that are located on opposite sides or that are separated by a spur dike.

Water quality constraints become important whenever dimensionless average flow rate, Q*, times the hydraulic efficiency correction factor, HECF , exceeds V* . A number of microcomputer spreadsheet simulations may be run to determine the most cost-effective CDF design that meets water quality constraints.

References

Shields, F. D., Schroeder, P. R., Thackston, E. L., and Bach, D. P. 1987. "Design and Management of Dredged Material Containment Areas to Improve Hydraulic Performance," Technical Report D-87-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Headquarters, US Army Corps of Engineers. 1987. "Confined Disposal of Dredged Material," Engineer Manual EM 1110-2-5027, Washington, DC.